ELECTRIC RAILWAYS.

(PART 4.)

CALCULATION OF FEEDERS.

1. In the transmission of current for electric railways, as in other cases of electric transmission, we are usually limited to a certain amount of loss or drop in the line. If the loss is large, we can use a comparatively high-resistance line with a corresponding small amount of copper. A large line drop, however, means a low voltage at the cars unless the voltage at the station is automatically increased as the load increases. Low line voltage makes it hard for the cars to maintain their schedule and always gives rise to trouble with the motors, to say nothing of the actual cost of the power wasted in the line. It does not pay, therefore, to allow the line loss to become excessive, and the feeders must be designed to keep the drop within the specified amount. The average percentage loss may vary greatly. It is seldom that the drop is less than 10 per cent. (50 volts), and in a great many cases it runs much higher than this.

2. The weight of the rail is fixed by traffic considerations, so that an approximate estimate of what the drop in the return circuit will be can be formed at the outset. The balance of the drop will then give that allowed for the feeders, and they should be designed to conform to this as nearly as possible. Feeders designed under this condition seldom fail to fulfil the requirements of the average drop.

There is a great difference between the maximum and average loads in the stations, and the smaller the station, the greater the difference is liable to be. For this reason, the average drop and maximum drop may be widely different. Take a case where the road operates only two or three cars and the load fluctuates between zero and the maximum several times in perhaps a minute. Before the size can be assigned to the feeders, the average load that each feeder has to look after must be approximately known or ascertained. In doing this, it is very convenient to divide the line into sections, assign to each section the load that probably will be on it, and proportion the feeders accordingly. Incidental to this method, a certain maximum drop or average drop must be assigned to each of the feeders, so that the operation of the cars on all sections of the line will be practicable under all ordinary conditions.

3. Estimation of Load. — In assigning the probable loads to the several sections, some knowledge must be had of the number of cars that are to be run and of their headway or distribution. A knowledge of the weight of the car and its equipment is also necessary in order to determine the current that the car will take under average conditions. As far as the *relative* sizes of the feeders and their points of feeding are concerned, any convenient unit of current per car can be selected, but in order to determine the *actual* size of the feeder in order to keep the drop within the specified amount, its actual load in amperes must be at least approximately known.

4. Rules for obtaining the current required under different conditions have already been given in *Electric Railways*, Part 2. The current, if supplied at a fixed voltage, is almost, if not quite, proportional to the speed of the car. Not only the variable speed at which the cars will run, but other things will tend to make the current required per ton a variable quantity, so that unless the road is already in operation and the average current consumption per car is known or can be found out, it will be necessary to know the style of car, motors, etc., and the conditions under which they are to be run, or to take this value from the experience of others. Let us assume a 24-foot car body equipped with 37-horsepower motors and call the average current per car throughout the day 20 amperes. This may strike one as a very low value when compared to the current called for when the two motors run at their rated output, but it must be borne in mind that a great deal of the time the car takes no current at all, for it may be coasting or standing still with the power off. The value of the average current per car is obtained by taking current readings on the car at regular intervals throughout several characteristic trips. The closer these readings are taken together, the more accurate will be the result. These current values are all added together and divided by the number of readings, and this gives the average of the current during the time covered by the test. This test should be made at a number of different hours during the day and the average value of all these average results taken. This final average is the load to be assigned to each of the several cars; this load multiplied by the number of cars to be run gives the average load of the whole road, or the load that the feeders will be called on to handle. The car referred to above is of medium size. Large double-truck cars would take a much larger current, the average probably being from 50 to 75 amperes, depending on the grades, etc.

5. Example of Feeder Calculation.—On account of its mechanical strength, low cost of maintenance, and good conductivity, the trolley wire in the following calculations will be assumed to be No. 00 hard-drawn copper having a resistance of about .08 ohm per 1,000 feet. This value covers the average conditions of temperature.

Fig. 1 shows the layout of a road that we will assume to be 5 miles long. The system is fed from a power station at one end of the line and operates ten cars using on an average 20 amperes of current per car, making a total of 200 amperes. It is prescribed that the total load *concentrated at the end of the line* shall not produce a drop of over 100 volts. If the trolley wire is No. 00, what must be the size of the feeder *B A* ?

The road is single track, so that there is available the conductivity of two lines of rails in the return circuit. These rails will be 5 miles long, and at .0111 ohm per 1,000 feet, including bonds, will measure .0586 ohm per mile; 5 miles of track will, therefore, measure $.0586 \times 5 = .293$ ohm,

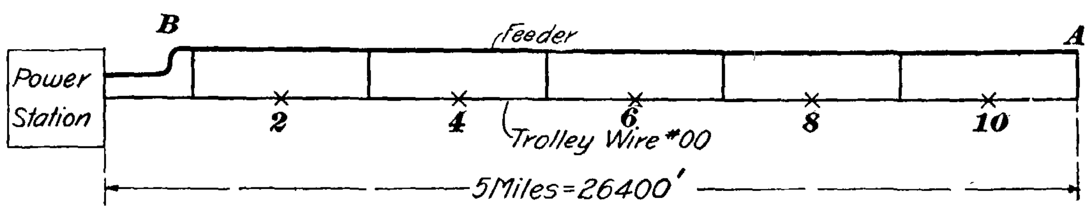

FIG. 1.

which resistance, carrying a current of 200 amperes, will cause a drop of $200 \times .293 = 58.6$ volts, leaving a drop of $100 - 58.6 = 41.4$ volts to take place in the trolley wire and feeder. If we assume that the conductivity of the copper in the trolley wire is the same as that in the feed wire, we may use the formula

$$\text{Circular mils} = \frac{10.8 \times L \times C}{e}, \qquad \textbf{(1.)}$$

where L = length of wire in feet through which the current C is delivered;
C = current supplied;
e = drop in volts.

The number of circular mils given by this formula will be the combined cross-section of the trolley and feeder, because these two wires are tied together in parallel throughout their length. In this case, $L = 26{,}400$ feet, $C = 200$ amperes, $e = 41.4$ volts; hence,

$$\text{Circular mils} = \frac{10.8 \times 26{,}400 \times 200}{41.4} = 1{,}377{,}400, \text{ nearly.}$$

The trolley wire is No. 00 and has an area of cross-section of 133,079 circular mils, as will be seen by referring to the wire table in *Electric Transmission*, Part 1. Deducting this from the total cross-section called for, leaves 1,377,400 − 133,079 = 1,244,321. This will be a very large feeder, and 5 miles of it would be very expensive.

6. Another Solution of the Same Problem.—In the above we assumed that the trolley wire was of practically the same quality of copper as the feeder. This makes the solution simple and accurate enough for all practical purposes, because the trolley wire is small compared with the feeder. We will assume that the hard-drawn trolley wire has a resistance of .08 ohm per 1,000 feet, which is somewhat higher than the resistance of a soft-copper wire of the same size, and work out the example by a different method in order to compare results.

The drop in the overhead system is limited to 41.4 volts, and as the current is 200 amperes, the resistance must be $R = \frac{41.4}{200} = .207$ ohm. The total resistance of the trolley wire itself is $.08 \times \frac{26400}{1000} = 2.112$ ohms. The feeder must then be of such a size that when it is connected in parallel with a resistance of 2.112 ohms, it will bring the combined resistance of the two down to .207 ohm. If R is the combined resistance of the two resistances R_1 and R_2 connected in parallel, then

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}.$$

Since we know the values of R and R_1, it is necessary to solve the above equation for R_2. The above equation may be transposed as follows:

$$\frac{1}{R} - \frac{1}{R_1} = \frac{1}{R_2}.$$

This equation, by reducing the left-hand side to a common denominator and then inverting the fractions, may be transformed so as to give

$$R_2 = \frac{R \times R_1}{R_1 - R}.$$

Since $R = .207$ and $R_1 = 2.112$, we get, by substituting these values in the last expression,

$$R_2 = \frac{.207 \times 2.112}{2.112 - .207} = .229.$$

Five miles of the feeder must then measure only .229 ohm. We have the general formula

$$R = \frac{10.8 \times L}{\text{cir. mils}},$$

where R = resistance of a copper wire;
L = length of the wire in feet;
cir. mils = area of cross-section of the wire in circular mils.

Or, we may write

$$\text{Circular mils} = \frac{10.8 \times L}{R}, \qquad \textbf{(2.)}$$

and in this case

$$\text{Circular mils} = \frac{10.8 \times 26{,}400}{.229} = 1{,}245{,}065.$$

This, it will be noticed, is a slightly larger cross-section than was called for by the previous method, but the difference is not of practical importance for a cable of such large size. Formula **1** is accurate enough for general use and gives the simplest means of getting at the required feeder cross-section.

7. The student should note particularly that in working the above example a fair value for the track resistance was assumed and the drop in the track circuit then estimated. This drop was subtracted from the total drop, thus giving the value e used in formula **1.** Formula **1** does not, therefore, in itself take the track resistance into account.

In the last example it was found that a very large feeder was needed to meet the requirements. Of course, these requirements were severe, because the drop was not to exceed 100 volts when all the cars were bunched at the end of the line. In most cases the cars would be moving along over different sections of the line, and this would lessen the drop on the system, because some of the cars would be comparatively near the station. At the same time, conditions arise where the cars may all be bunched at the end. In this particular case, therefore, it would be well to raise the voltage to 600 at full load at the station, either by using a very heavily overcompounded generator or by using a booster.

8. Example With Power House in Middle of Line.—If the power house were situated at the middle of the line, the amount of copper required would be very much less, as will be easily seen by referring to Fig. 2. The limiting condition is the same as before; that is, the drop from S to A or B must not exceed 100 volts when all the cars are concentrated at either A or B. If the cars are bunched at either A or B, 200 amperes must be transmitted through $2\frac{1}{2}$ miles

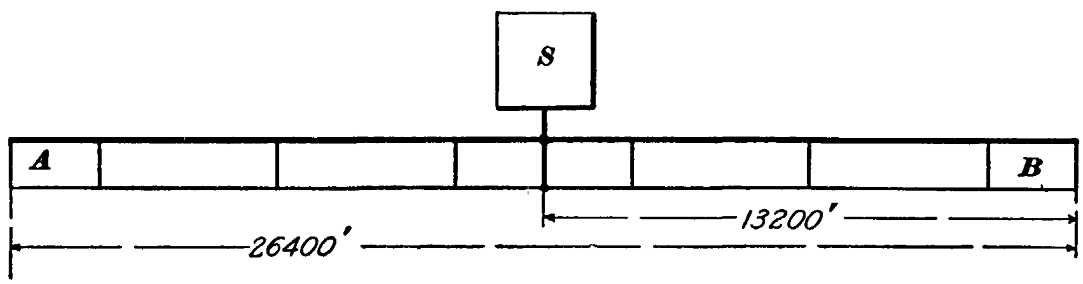

FIG. 2.

of track and feeder. Taking the track resistance as .0111 ohm per 1,000 feet, the resistance of $2\frac{1}{2}$ miles of track will be $\frac{13200}{1000} \times .0111 = .1465$ ohm. The drop in the track part of the circuit will, therefore, be $.1465 \times 200 = 29.3$ volts. This leaves a drop of $100 - 29.3 = 70.7$ volts to take place in the feeder and trolley wire. The length of feeder and trolley wire is $2\frac{1}{2}$ miles; hence, by applying formula **1**, we have the combined cross-section of the two,

$$\text{Circular mils} = \frac{10.8 \times 13{,}200 \times 200}{70.7} = 403{,}281.$$

The trolley wire supplies 133,079 circular mils of this cross-section; hence, the cross-section of feeder required is $403{,}281 - 133{,}079 = 270{,}202$. It is easily seen that placing the power house near the middle of the line results in a very large reduction in the amount of copper required.

9. It may be of interest, in passing, to see what the effect would be in the above two cases if the feeder were done away with altogether and the trolley wire increased in size to No. 0000. In the first case, 200 amperes would be transmitted over 5 miles of trolley wire. No. 0000 trolley wire has a resistance of about .05 ohm per 1,000 feet. Five miles of No. 0000 wire would, therefore, measure 1.32 ohms. A current of 200 amperes through this resistance would cause a drop of $200 \times 1.32 = 264$ volts, which, even if the power-house voltage were maintained at 600, would leave only 336 volts for the operation of the cars, to say nothing of the drop in the track part of the circuit, and this would not be sufficient for satisfactory operation.

In the second case, with the power house at the middle of the line, the drop in the trolley wire would be only one-half as great, because the wire would be only one-half as long, but even then the drop would amount to 132 volts in the trolley wire or $132 + 29.3 = 161.3$ volts altogether. If the station voltage were the standard 500 volts, the pressure at the cars would then be $500 - 161.3 = 338.7$ volts, which would not be sufficient to run the cars on schedule time. If, however, the power-house voltage could be raised to 600 at full load, a pressure of 438.7 volts would be obtained at the cars. This voltage, while not as economical from the car-operation point of view as it should be, is entirely practicable, as there are very few roads where the voltage under conditions of concentrated end load is as high as 475 volts.

10. Effect of Distributed Load.—So far we have worked out these feeder problems on the assumption that the load was bunched at one end. This is a condition that sometimes arises in practice, but it can hardly be looked on as the ordinary operating condition. In most cases we have a number of cars spaced at fairly regular intervals along the line, each car moving at an approximately uniform rate. The result of this is that current is taken off at a number of points that are continually shifting along the line. The load is practically uniformly distributed and there is a gradual falling off in current from the station to the end of the line. For example, suppose *A B*, Fig. 3, represents a stretch of line that supplies six uniformly spaced cars moving at a uniform speed and taking 20 amperes per car. On account of the uniform movement and even spacing, the current will decrease gradually from 120 amperes at the station to zero at the end *B*. We may represent the falling off in the current by the line *C B*. The drop between *A* and *B* will, therefore, be found by multiplying the average current in *A B* by the resistance. The average current is evidently one-half the station current, or 60 amperes; hence, if the resistance of *A B* were, say, $\frac{1}{2}$ ohm, the drop between *A* and *B* would be 30 volts. If the whole load were

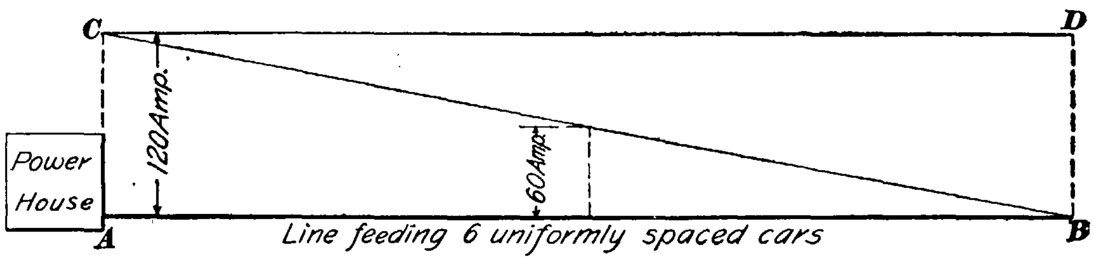

FIG. 3.

bunched at *B*, the current would be 120 amperes throughout the whole length, as represented by the line *C D*, and the average current throughout the length would be the same as the current at the station; hence, the drop would be $120 \times \frac{1}{2} = 60$ volts. From the above, it may be stated that *for a given line wire and a given amount of current transmitted, the drop with a uniformly distributed load is one-half that with a concentrated end load.* In other words, if we are making calculations relating to a distributed load and consider the whole length of line in our calculations, we must take the current as one-half the actual current supplied to all the cars, because the current falls off as previously described from the station, or feeding point, to the end of the line.

Another and perhaps a better way of considering a distributed load is to look on it as if the whole load were concentrated at the middle of the line and work out the problem as if the whole current were transmitted over half the line.

11. Example of Calculations for Distributed Load. Taking the road shown in Fig. 1, find what size of feeder will be required when the load is distributed and also when the drop to the end of the line is limited to, say, 50 volts. Here 50 volts has been taken as the allowable drop, as this is a common value aimed at in practice.

There are ten cars, each taking 20 amperes and uniformly spaced; the whole load of 200 amperes may be considered as being concentrated at the middle of the line, or it may be considered that an average current of 100 amperes is transmitted over the whole line. In order to be definite, we will choose the former and simply work the problem as if 200 amperes had to be transmitted through $2\frac{1}{2}$ miles of feeder and $2\frac{1}{2}$ miles of track with a drop of 50 volts. The track resistance was found to be .0586 ohm per mile, so that the resistance of $2\frac{1}{2}$ miles of track will be $.0586 \times 2.5 = .1465$, and the drop in the track $= .1465 \times 200 = 29.3$ volts. This leaves $50 - 29.3 = 20.7$ volts drop for the feeder and trolley. Then the combined cross-section of the feeder and trolley will be

$$\text{Circular mils} = \frac{10.8 \times 13{,}200 \times 200}{20.7} = 1{,}377{,}400.$$

It will be noticed that this combined cross-section is the same as that found necessary to supply an end load with a drop of 100 volts. In other words, with the same amount of line copper a uniformly distributed load will produce only one-half the drop that a bunched end load will cause, or if the drop is kept the same in both cases, the amount of copper required for the distributed load will be only one-half that called for by the concentrated load.

With the system shown in Fig. 1 and a combined cross-section of feeder and trolley of 1,377,400 circular mils, there will be a drop of 50 volts when the cars are uniformly distributed, and if for any reason it becomes necessary to bunch the cars all at one end, the drop will become 100 volts.

The method of working out the case shown in Fig. 2 will be the same as the above except that the current supplied each side of the station will be only 100 amperes, because the load is uniformly distributed and one-half the cars will be on each side. Also, this 100 amperes will be considered as concentrated at the middle of the 13,200 feet. This will require much less copper than when the load is concentrated at either end. In the above, the student must not forget that although we have considered the load as bunched at the middle of the line, the feeder runs the whole length, as indicated in the figures.

12. Example of Calculations for a Loop Line.—Fig. 4 represents a so-called **loop line** that runs down one street and comes up at the next street parallel to it. It is a modified form of the **belt line** that is supposed to encircle the business part of the city, but it differs from a

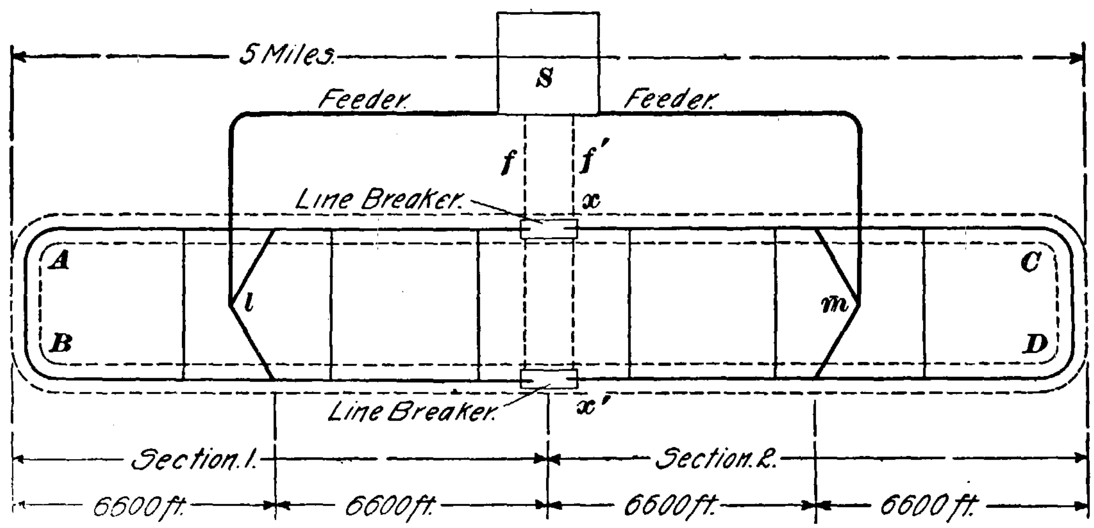

FIG. 4.

belt line in that, since the parallel lines are in neighboring parallel streets, the power house can, without great sacrifice of economy, be placed to one side of the area enclosed by the system, instead of being placed within this area.

In Fig. 4, *A C* is the street that the cars go up, *D B* the street on which they return. It must be noted that the area enclosed by the two tracks is very long in comparison to its width. The width between the streets is exaggerated in Fig. 4 in order to make the arrangement clearer. As a matter of fact, the loop would be very long and narrow.

The full line indicates the path of the trolley wire and the dotted lines that of the track. The two trolley wires are tied together at intervals so as to equalize the current between them; the rails are likewise tied together. The two heavy full lines running to the right and left of the power house indicate the two feeders that are tapped into both trolley wires at the middle of the sections. It is assumed that the trolley line is divided into two sections by the line breakers x, x' and that each feeder feeds in at the middle point of the sections. Since the two sections are independent and since each is supplied by its own feeder, we can calculate one of the feeders; the other will be the same, because the road is symmetrical. Since the cars are supposed to be uniformly distributed, the load on each section may be considered as being concentrated at the middle of that section, that is, in this case, where the feeders are attached. Taking each section by itself, it will be seen that this problem is similar in many ways to the last one worked out. Let us assume that the specifications require that the drop from the station to the feeding-in points l, m shall not exceed 50 volts when the cars are taking their average current and are uniformly distributed. A total of ten cars is operated and each car takes 20 amperes. The number of cars on each of the two sections will, therefore, be five and each feeder will have to supply 100 amperes. Since the trolley wire is fed from the middle point of each section and there are no feeders on the end of the section, there will always be more or less drop in the trolley wire itself. This drop will not, however, amount to much, as the distance from l to the end of the line or to the line breakers is short and there cannot be more than two cars in any one of these sections of trolley wire at the same time. The length of a section is $2\frac{1}{2}$ miles, or 13,200 feet; a half section is 6,600 feet, and a quarter section is 3,300 feet. For the present we will omit any consideration of the loss in the quarter section of double trolley wire and simply conform to the requirements of the limiting condition. The resistance through which the drop of 50 volts is to take place is that of four lines of single rail well bonded together and the feed wire, both of which are $1\frac{1}{4}$ miles long. The current at which this drop will take place is 100 amperes. The resistance of $1\frac{1}{4}$ miles (6,600 feet) of double track is $6.6 \times .0056 = .037$ ohm, because the resistance of 1,000 feet of single 80-pound rail is .0223 ohm, so that the resistance of 1,000 ft. of single track, four rails in multiple, is $.0223 \div 4 = .0056$ ohm. A current of 100 amperes through a resistance of .037 ohm causes a drop of $100 \times .037 = 3.7$ volts. The total drop is limited to 50 volts, so that the drop in the feeders must be $50 - 3.7 = 46.3$ volts. The length of the feeder is 6,600 feet, so that we have

$$\text{Circular mils} = \frac{10.8 \times 6{,}600 \times 100}{46.3} = 154{,}000, \text{ nearly.}$$

A No. 000 B. & S. wire has a cross-section of 167,805 circular mils, so this size would probably be used, and $2\frac{1}{2}$ miles of this feeder would be needed to equip the road.

13. In the layout shown in Fig. 4, the trolley wires are not fed on the ends at all, and should the five cars on a section become bunched at one end there would be quite a drop in voltage in the trolley wire in addition to the drop in the feeder. Suppose all cars on section *2* to be bunched at *C*; a total current of 100 amperes will have to be supplied to these cars, and this current will have to flow through $1\frac{1}{4}$ miles of double trolley wire and back to the power house through the double track. The drop in the $1\frac{1}{4}$ mile of double track from *m* to *C* will be very small, so we will confine our attention to the drop in the trolley wire. Taking the resistance of the trolley wire as .08 ohm per 1,000 feet, $1\frac{1}{4}$ miles will have a resistance of $\frac{6600}{1000} \times .08 = .52$ ohm, approximately. There are, however, two trolley wires in multiple, so that the resistance from *m* to *C* will be .26 ohm; and, with a current of 100 amperes, the drop will be $100 \times .26 = 26$ volts. This drop, it must be remembered, will only occur under the extreme condition where the five cars on a section are all bunched at one end. Under normal conditions, the drop in the trolley will not be more than one-quarter of this amount, or about 6.5 volts. This, together with the 50 volts loss allowed in the feeding system, will make the total average drop in the overhead system about 56.5 volts. If the voltage at the station is maintained at 500 volts, this will leave a pressure of 443.5 volts at the cars. However, most railway generators are overcompounded to give a rise of at least 10 per cent. in voltage from no load to full load, and with a machine of this kind the voltage at the cars will drop but little under 500.

Another way to allow for the trolley-wire loss is to make the feeder a little larger. In this case, increasing the size to No. 0000 will be sufficient, but unless there is a prospect of some future extension to the road or an increase in the number of cars, the best thing to do is to run the dynamos at a little higher voltage.

14. In Fig. 4, suppose we connect two feeders *f*, *f'*, indicated by the dotted lines, one to each section, directly from the power house, and see what effect this will have on the voltage supplied to the cars. In practice, it will cost but little to do this, because these feeders will be very short. Consider one of the sections, say, section *1*. It is fed by the regular feeder previously calculated, and, in addition, the feeder *f* runs out directly from the power house and is tapped on the trolley wire at the line breaker. We will find what the drop would be under the most unfavorable conditions, that is, with the five cars on the section bunched at *A*. The whole current, 100 amperes, will have to return to the station through $2\frac{1}{2}$ miles of double track. In the overhead work there will be $1\frac{1}{4}$ miles of feed wire, and in multiple with this will be the two trolley wires extending back to the station, because the connection of the feeder *f* puts the trolley wires in multiple with the regular feeder. Up to the point *l*, therefore, we have the feeder and the two trolley wires in multiple to carry the current. Beyond *l*, to the end of the line, the current is carried by the two trolley wires alone.

The resistance of $2\frac{1}{2}$ miles of double track, assuming the resistance per 1,000 feet to be .0056 as before, will be .074 ohm. The resistance of $1\frac{1}{4}$ miles of two No. 00 trolley wires in multiple, if a single No. 00 hard-drawn copper wire measures .08 ohm per 1,000 feet, will be

$$\frac{.08}{1{,}000} \times 5{,}280 \times 1\tfrac{1}{4} \times \tfrac{1}{2} = .26 \text{ ohm.}$$

The resistance of $1\frac{1}{4}$ miles of No. 000 feeder wire is about .41 ohm, and this in parallel with the resistance of $1\frac{1}{4}$ miles of double trolley gives the resistance from the station to the point l as

$$\frac{.26 \times .41}{.26 + .41} = .16 \text{ ohm.}$$

The total resistance to the end of the line and return will then be $.074 + .26 + .16 = .494$ ohm. This will give a drop of 49.4 volts with a current of 100 amperes. It is thus seen that where the load is bunched at the far end, the addition of the feeders at the station does not improve the drop very much, because without the use of these feeders the drop would be about 56.5 volts. If, however, the load should become bunched at, say, l, the point where the feeder taps in, the track resistance will be .037, and the combined resistance of the feeder and trolley wires .16, making a total resistance of .197 ohm, and the drop will be only 19.7 volts as against 46.3 volts if the feeder alone were used. If the load were concentrated at the power-station end of the section, there would be little or no resistance in the circuit, save that of the tap wire and the ground-connection wire, so it is safe to say that the loss caused by a current of 100 amperes would not at this point be more than 5 volts. It is easily seen, then, that the effect of tapping the feeder in at the power-station end of the section and thereby getting the full benefit of the conductivity of the trolley wire is a good move, as it results in lowering the voltage loss due to resistance. The power-house taps, as well as the line feeder, must be provided with feeder switches, so that the current may be cut off any section desired.

15. Loop Line Supplied by Four Feeders.—In the last illustration it was shown that the introduction of taps, or short feeders running into the power house, had the effect of keeping up the voltage on all parts of the line to some extent, but that the effect was most pronounced on the part of the line comparatively near the power house. By adopting a little different method of feeding, we can keep the voltage more uniform at all points. In Fig. 4, it will be noticed that the feeding-in points are, as it were, lopsided. In other words, most of

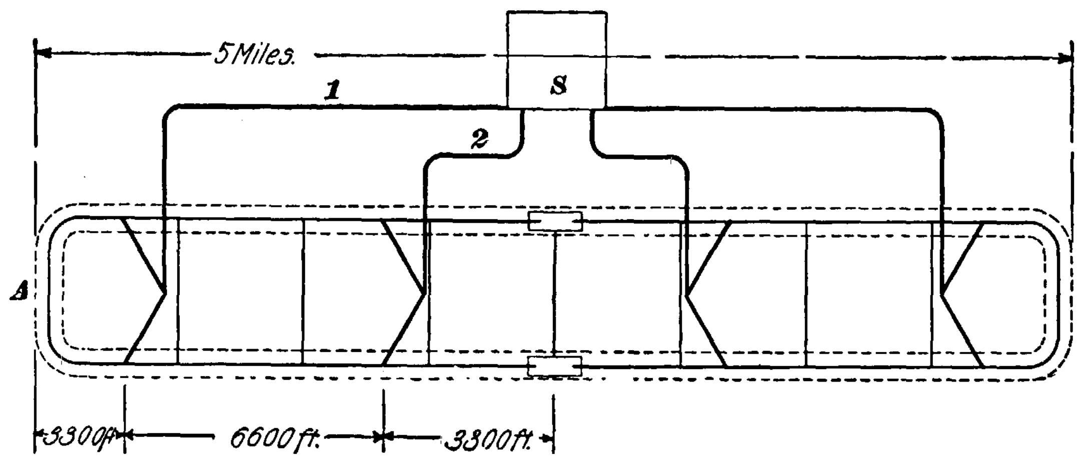

FIG. 5.

the feeding-in is done on the half of the section nearest the power house. We will, therefore, extend the feeders as shown in Fig. 5, and have the two points where the current is fed in 6,600 feet apart as before, but situated 3,300 feet, or $\frac{1}{4}$ section, from each end. The point where feeder *1* taps in will then be 9,900 feet from the station, and the point where feeder *2* taps in 3,300 feet from the station. The length of trolley wire projecting beyond the taps on both ends will be 3,300 feet.

As before, we will first see what the drop will be if the five cars are bunched at the end *A*. The current will have to come back through 13,200 feet of double track, which, as before calculated, has a resistance of .074 ohm. The flow of the current in the overhead work is somewhat more complex. In the first place, there are 3,300 feet of double trolley wire on the far end of the line; this will have a resistance of $.08 \times \frac{1}{2}$

$\times \frac{3300}{1000} = .13$ ohm. Next, the short feeder *2*, which we will suppose is the same size as *1*, is 3,300 feet long and is in series with 6,600 feet of double No. 00 trolley wire, and these two in series are in multiple with the long feeder *1*. No. 000 wire has a resistance of about .062 ohm per 1,000 feet. Feeder *1* is 9,900 feet long and has a resistance of $9.9 \times .062 = .614$ ohm. The resistance of the short feeder and double trolley wire combined is $3.3 \times .062 + \frac{6.6 \times .08}{2}$ $= .469$ ohm. This is in multiple with the feeder whose resistance is .614 ohm; hence, the combined resistance of the two will be

$$\frac{R_1 \times R_2}{R_1 + R_2} = \frac{.469 \times .614}{.469 + .614} = .26 \text{ ohm.}$$

The total resistance from the power house to the end of the line and back again will then be $.13 + .26 + .074 = .464$ ohm, and with a current of 100 amperes the drop will be 46.4 volts. This is better than was obtained with the first layout considered in connection with Fig. 4, where there was 50 volts drop to the feeding-in point and 26 volts more through the trolley wire.

16. Next, suppose the whole load to be located just at the long feeder tap. In this case the resistance is the same as before less the resistance of 3,300 feet of double trolley wire on the end and 3,300 feet of track. The resistance of 9,900 feet of rail return is $9.9 \times .0056 = .055$ ohm, nearly. The whole resistance will then be $.055 + .26 = .315$ ohm, and the drop will amount to $.315 \times 100 = 31.5$ volts.

17. If the whole load is located at a point midway between the two feeder taps, each feeder will have the same length of trolley wire in series with it and the two sets will be in multiple; also, there will be 6,600 feet of track in the circuit. The resistance of the long feeder and its 3,300 feet of double trolley will be $.614 + .13 = .744$ ohm. The resistance of the short feeder and its 3,300 feet of trolley wire will be .205 + .13 = .335 ohm, and the resistance of the two sets in multiple will be $\frac{.335 \times .744}{.335 + .744} = .231$ ohm, nearly. The resistance of the track will be .037 ohm, thus giving a total resistance of .231 + .037 = .268 ohm for the whole circuit. This will cause a drop of 26.8 volts with the load concentrated between the taps.

18. If the load is just at the end of the short feeder tap, the circuit resistance will be distributed as follows: There will be 3,300 feet of rail return, and the long feeder will be in series with 6,600 feet of double trolley wire, and the two together will be in multiple with the short feeder. The working out of the drop in this case is left as an exercise for the student. It is in the neighborhood of 18 volts.

If the load is somewhere near the line breaker in front of the station, the loss is increased by 13 volts on account of the trolley wire between the tap and the line breaker. On the other hand, the drop will be decreased by nearly 2 volts, because there is no track included in the circuit with the load in front of the station. The net increase will therefore be about 11 volts.

The general effect of using the two feeders is to equalize the voltage on the system, thus enabling the cars to maintain a uniform speed.

The above simple examples have been selected to show the student how ordinary feeder calculations may be made. They do not, of course, cover the whole field of feeder design, but the principles and methods of calculating here given should enable one who is at all inclined to look into the subject to investigate and possibly improve the working conditions on a road of moderate size.

19. Comparison Between Track Resistance and Overhead Resistance.—As already stated, it is difficult to estimate the resistance of the track closely even if the weight of the rails is known, because the bond resistance is uncertain. Formerly, in making line calculations, it was assumed that the track circuit had no resistance, but, as previously pointed out, this was far from the truth. Very often the resistance of the track circuit is taken as about $\frac{1}{4}$ that of the overhead circuit, but it is evident that no general relation between the two can be given, because, in the first place, the size of the rails may vary in different cases, and in the second place, the amount of copper put in the overhead line varies within wide limits, depending on the nature of the traffic and the amount of loss allowed.

The ordinary formula that we have been using for making feeder calculations,

$$\text{Circular mils} = \frac{10.8 \times L \times C}{e},$$

applies, as it stands, to the copper part of the circuit only, and the length L refers to the length of the copper part of the circuit through which the current C flows. If we know the relative amount of resistance in the track as compared with that in the line, we can modify this formula so as to take account of the resistance of the rail return. A formula of this kind is very convenient for making approximate calculations. According to Dr. Louis Bell, a constant of 14.4 instead of 10.8 will allow approximately for the resistance of the track return, thus giving the formula

$$\text{Circular mils} = \frac{14.4 \times L \times C}{e}. \qquad \textbf{(3.)}$$

This means that under average conditions of load and track-return resistance *the cross-section in circular mils of a feeder necessary to deliver a current C with a drop e is equal to 14.4 times the length of the feeder in feet times the current divided by the volts drop.*

It must not be forgotten that this formula is not exact in all cases; it merely represents average conditions. The constant appearing in the formula is found to lie between 14 and 15 on the great majority of roads as ordinarily built.

20. In order to further illustrate feeder calculations, we will work out the case of a small road and at the same time make use of formula **3** in order to illustrate its application.

EXAMPLE.—Fig. 6 shows the layout of a single-track road operating nine cars, which are spaced fairly evenly along the line. The road is divided into two sections by means of a line breaker. Each section is provided with a No. 000 main, as indicated, and these mains are fed by two feeders *1* and *2* running from the power station. The drop under average conditions is to be limited to 50 volts. Each car takes an average current of 20 amperes.

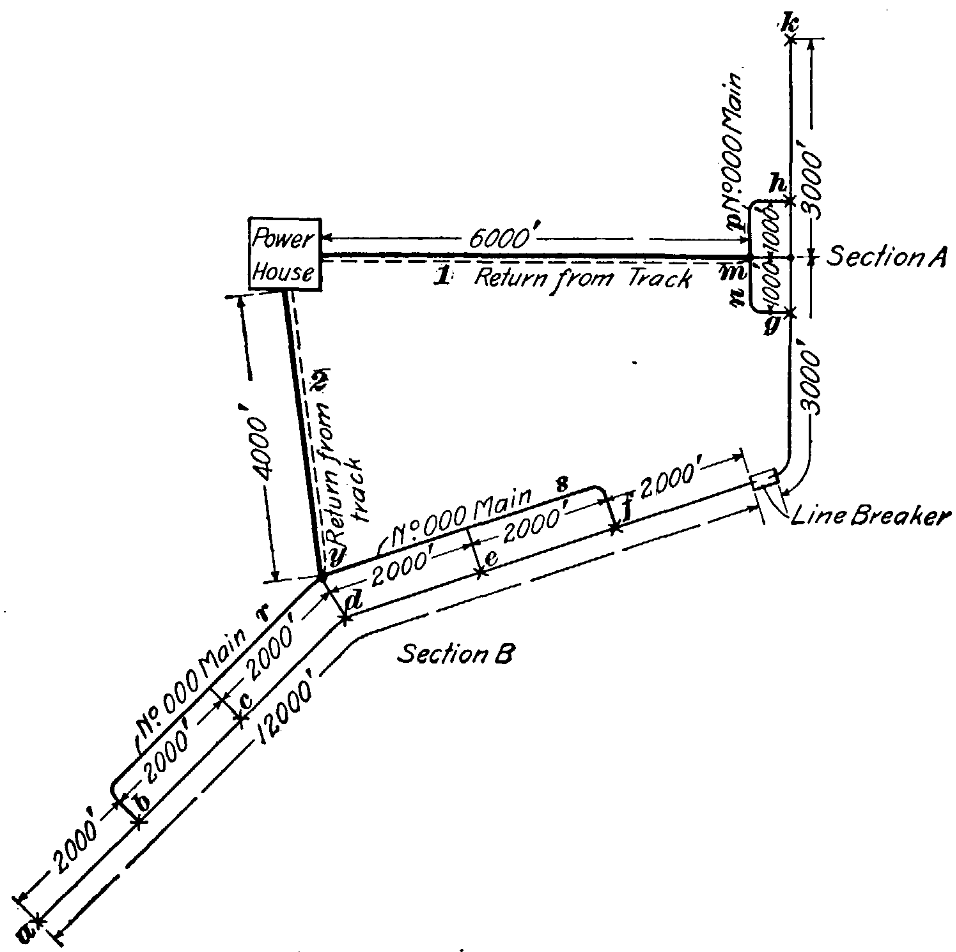

FIG. 6.

SOLUTION.—Since the cars are equally spaced and constantly shifting in position, the drop will vary somewhat, depending on the position of the cars. In order to make things definite, we will assume that the cars are located as shown by the crosses. This will represent a fair average condition, and the drop for other positions will not be greatly different unless the cars become bunched in some particular spot. If we design the feeders so that the drop from the power house to cars *a* and *k* shall not exceed 50 volts, it is evident that the drop to the other cars will fall under the prescribed 50 volts, because cars *a* and *k* are the most distant from the station. No track resistance is specified, so we will make use of formula **3** in estimating the drop in those parts of the circuit that include a track return. We will first take section *A* and determine the size of feeder *1*.

Section A.—The road operates nine cars and is 18,000 feet in length; hence, there will be one car for every 2,000 feet. Section *A* will have three cars and the current supplied by feeder *1* will be 60 amperes. The size of the trolley wire and its distributing main is fixed, so that we must first determine the drop in this part and then see what is left for the drop in the outgoing and return feeders. It is easily seen that return feeders from the track must be used, because the power house is some distance from the track and the ground cannot be depended on to carry the current. The return feeders may be strung either on poles or placed underground. We will first determine the drop from *h* to *k*. To do this we have the formula

$$\text{Circular mils} = \frac{14.4 \times L \times C}{e}.$$

In this case, however, we know the number of circular mils in the cross-section of the trolley wire and wish to find e; so, transposing the formula, it becomes

$$\text{Drop } e = \frac{14.4 \times L \times C}{\text{cir. mils}}.$$

In this case, L (distance from *h* to *k*) $= 2{,}000$ feet, $C = 20$ amperes, and the circular mils of No. 00 wire = about 133,000;

hence, $$\text{Drop } e = \frac{14.4 \times 2{,}000 \times 20}{133{,}000} = 4.3 \text{ volts.}$$

The drop from the feeding-in point *m* to the point *h* is next calculated. The cross-section of the wire carrying the current is that of the main (No. 000) plus that of the trolley (No. 00). The total number of circular mils is then, approximately, $167{,}800 + 133{,}000 = 300{,}800$. The distance is 1,000 feet and the current is 40 amperes;

hence, $$\text{Drop } e = \frac{14.4 \times 1{,}000 \times 40}{300{,}800} = 1.9 \text{ volts.}$$

The total drop from *m* to *k* is, therefore, $4.3 + 1.9 = 6.2$ volts. This leaves $50 - 6.2 = 43.8$ volts drop for the outgoing and return feeders combined.

Feeder *1* with its return feeder will have to carry current for three cars, i. e., 60 amperes, and this current must be carried over $6{,}000 \times 2 = 12{,}000$ feet of wire. This part of the circuit will be of copper throughout and the same size of wire will be used both for the outgoing wire and the return. We have, then, using formula **1**,

$$\text{Circular mils (of outgoing and return feeders } \mathit{1}) = \frac{10.8 \times 12{,}000 \times 60}{43.8} = 177{,}500.$$

A No. 000 feeder comes nearest this, although it may be a trifle small. It might perhaps be better to install a No. 0000 feeder, for the reason that four cars might easily become bunched on section *A*, and, besides, it is well to have some margin for future extensions.

Section B.—The drop from *b* to *a* will be 4.3 volts, that is, the same as from *h* to *k* in section *A*. The drop from *c* to *b* will be twice that from *m* to *h*, because the size of conductor and the current are the same, but the distance is twice as long. The drop from *c* to *b* will, therefore, be $2 \times 1.9 = 3.8$ volts. Car *d* will cause no drop in the trolley or main, because its current is taken directly from the feeder. The drop from *d* to *c* will be that due to 60 amperes through 2,000 feet of combined trolley and main;

hence, $$\text{Drop from } d \text{ to } c = \frac{14.4 \times 2{,}000 \times 60}{300{,}800} = 5.7 \text{ volts.}$$

Total drop from y to $a = 4.3 + 3.8 + 5.7 = 13.8$ volts, and the total allowable drop in the outgoing and return feeders is $50 - 13.8 = 36.2$ volts.

The current in feeder *2* will be that due to six cars, i. e., 120 amperes; the total length of outgoing and return feeder will be $4{,}000 \times 2 = 8{,}000$ feet;

hence, Circular mils (of outgoing and return feeder *2*)

$$= \frac{10.8 \times 8{,}000 \times 120}{36.2} = 286{,}400.$$

This is larger than No. 0000. Two No. 00 wires will give about 266,000 circular mils, but the best plan will probably be to use a 300,000-circular-mil stranded cable, as this will allow some margin on the large side and involve less line work. The return feeder will, of course, also have an equal cross-section.

21. Carrying Capacity of Feeders.—In making these calculations, no attention has so far been paid to the carrying capacity of the wires and cables that have been used. Of course, this point must be kept in mind, because if the lines are simply figured out on the basis of giving the allowable drop, it might happen that the current will be sufficient to overheat the wires. The accompanying table gives the approximate amount of current that the wires may be allowed to carry without causing the temperature to increase much over 25° F. above that of the surrounding air. These values are given by Mr. H. W. Fisher, of the Standard Underground Cable Company.

No. B. & S. Gauge.	Circular Mils.	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately. Amperes.	No. B. & S. Gauge.	Circular Mils.	Carrying Capacity, With a Rise in Temperature of 25° F., Approximately. Amperes.
Stranded Cables.	500,000	509	2	66,370	124
Stranded Cables.	400,000	426	3	52,630	107
Stranded Cables.	350,000	388	4	41,740	91
Stranded Cables.	300,000	355	5	33,100	74
Stranded Cables.	250,000	319	6	26,250	63
0000	211,600	275	7	20,820	52
000	167,800	237	8	16,510	44
00	133,100	195	9	13,090	36
0	105,500	168	10	10,380	30
1	83,690	143			

In most cases, however, it will be found that the size of wire necessary to keep the drop within the specified limits will be considerably larger than that necessary to handle the current without overheating. Only in cases where the distances are short is there likelihood of the wire not being large enough. It is always well, however, to compare the sizes obtained and the current that the wires must carry with the values given in the table. If the wires should prove to be too small, the only thing to do is to use a wire that will carry the current safely or else run the risk of the wire overheating. If the larger wire is used, it will result in a somewhat smaller drop, but this will be an advantage, although the first cost of the wire will be a little higher.

22. Effects of Low Voltage.—In all the line and feeder calculations that have been made, the end in view has been to limit the drop to a certain amount. If the drop becomes excessive, either on account of the feeding system being too light or the load too heavy, it will produce a low voltage at the cars, and this in turn means low speed. It is a well-known fact that just as soon as the voltage on a system becomes low, troubles with the motors and car equipment begin to multiply. There are many cases on record where controller and brush-holder troubles have been very much decreased and where the roasting of field coils, controller blow-out coils, and the throwing of solder out of the commutator connections have been entirely stopped simply by raising the voltage on the line.

Let us suppose that a road having a certain number of cars is operated at, say, 550 volts and on a certain schedule. Suppose that, owing to an extension of the road, the addition of more cars, the deterioration of the track-return circuit, or any other reason, the voltage gradually comes down to 400. This will make a maximum decrease of about 20 per cent. in the running speed of the cars. If the time table is rearranged so that the motormen can run the cars on time with the same ease that they could with the higher voltage, the troubles with the rolling stock will not only not increase, but they will actually decrease, because the lower voltage is not as hard on the insulation and arc-breaking devices and the lower speed is not as hard on the car bodies and trucks.

If, on the other hand, no notice is taken of the gradual decrease in the average line voltage and the same time table is kept in force, the following will be the result: Since the maximum running speed of the cars has been cut down, the motorman must make up time wherever he can. Most of this will be made up at starting and getting the car under headway; part of it will also be made up on curves, crossings, and other places where, under ordinary conditions, slow running would be the rule. At starting, the controller is moved around rapidly and the car takes far more current than it should. This excessive current injures the controller, the commutator, and the brushes. The insulation on the fields becomes roasted and troubles of all kinds are liable to occur simply because the equipment has to be abused to make the car run on time.

As a practical instance of the result of low voltage, we may cite the following actual case that occurred where two abutting roads used each other's tracks for about ¾ mile. Their trolley wires were separated by a line breaker and each road had its own feeder system. On one side of the breaker the voltage was 425 volts; on the other side, 525 volts. As long as each road used only its own trolley wire the high-voltage road had no trouble to speak of. As soon as its cars began to run over the low-voltage road, controller and brush-holder breakdowns set in and continued until two extra feeders were run to the low-voltage side.

The above effects have been noted here simply to show that the question of proper voltage is an important one. It is true that there are many roads operating under an excessive drop, and this in itself is not so bad if the pressure at the station is increased so that the proper voltage at the cars is maintained. At the same time, a large drop means a large waste of power, and the question as to whether it will pay better to lose a considerable amount of power or buy more feed wire is something that must be determined by the relative cost of power and copper.

ELECTROLYSIS.

23. Introductory Remarks.—The subject of **electrolysis** is closely connected with the feeding system, especially the track-return part of it. By electrolysis in this connection is meant the eating away of the rails, underground pipes, or other buried metallic conductors by stray currents from the street-railway system. When electrolysis was first noticed, a great outcry was raised against the trolley roads by gas and water companies, telephone companies, and other corporations owning underground pipes or lead-covered cables. Many lawsuits were brought against electric-railway companies, and this led to an investigation of the subject. The result has been that electrolysis is not feared nearly as much as it once was, because means have been devised for avoiding it largely or for limiting it to sections where it can be watched or provision made to prevent it.

24. Elementary Principles.—In Fig. 7, *A* and *B* are two iron plates buried a short distance apart in damp earth. If the terminals of *A* and *B* are connected to a dynamo and a current is made to flow from *A* to *B* through the earth, we will find that plate *A* is eaten away or pitted, while plate *B* is not damaged. This is practically the same electrochemical effect that takes place in electroplating, where metal is taken from a plate or anode and deposited on the article to be plated. The point to notice is that wherever current flows *from* a metal conductor into the earth, the conductor is eaten away, but where current flows from the earth *into* the conductor, the latter is not damaged. The rate at which the metal will be eaten depends on the strength of the current. One ampere flowing steadily for 1 year will eat away about 20 pounds of iron or 75 pounds of lead, so that it is not hard to see that the damage due to this effect may be a very serious matter.

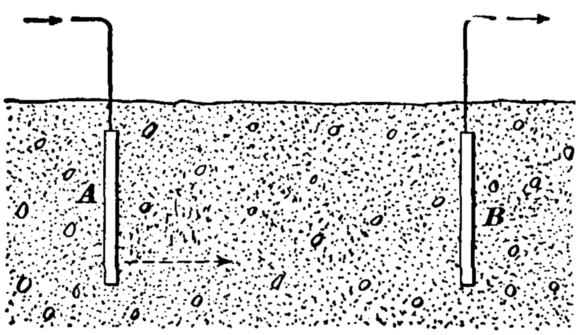

FIG. 7.

25. Electrolysis Due to Railway Currents.—Fig. 8 gives a simple illustration as to how electrolysis may occur in connection with an overhead-trolley system. *T T* is the trolley wire and *R R* the track. Under ordinary conditions, the current is supposed to return by way of the rail, as indicated by the arrows. If, however, there happens to be a pipe *L L* in the neighborhood of the track, and if this pipe offers a ready path for the current, part of the current will leave the rails, as at *I*, enter the pipe and flow out again at *O* to return to the power station. At *O*, where the current *leaves* the pipe, electrolytic action will be set up and in the course of time will eat holes in the pipe. At *I* the current leaves the rails; hence, the rails will be eaten away to some extent. If the trolley wire were connected to the negative pole of the dynamo instead of the positive, the current would flow out through the track, and whatever corrosion occurred on the pipes would take place at points

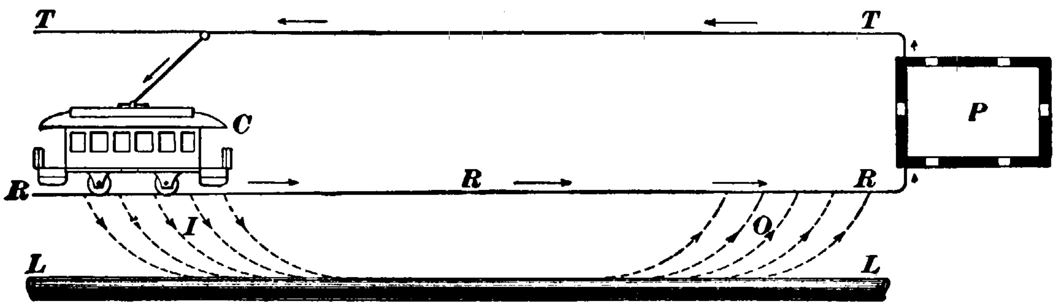

FIG. 8.

removed from the station and would be scattered over a wide area. On the other hand, with the positive pole connected to the trolley, whatever action takes place on the pipes is confined to districts near the power house. These areas are comparatively small, and measures can be taken to protect them. This is the principal reason why the positive pole of the dynamo should be connected to the trolley side of the line.

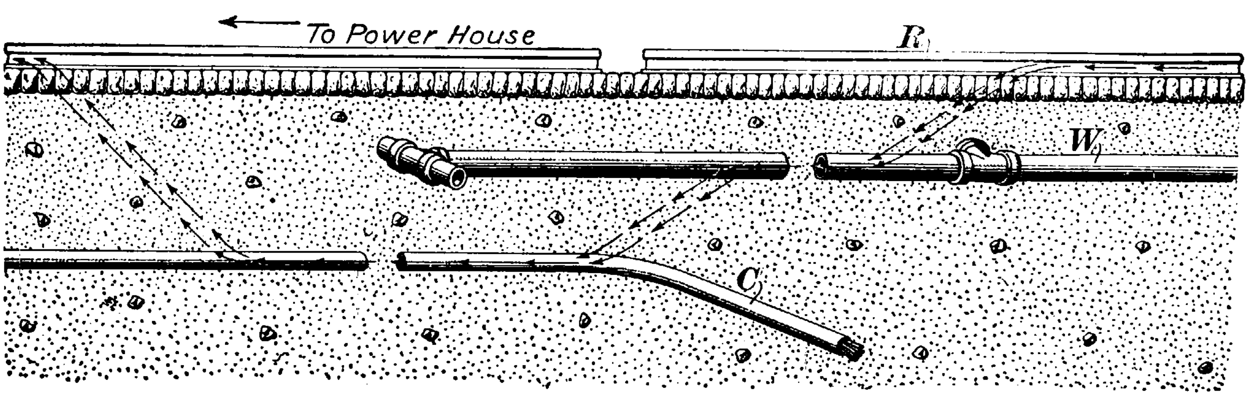

FIG. 9.

Figs. 9 and 10 show modifications of the simple case shown in Fig. 8. In Fig. 9, the current leaves the rail *R*, enters the pipe *W*, and flows through *W* until a better path presents itself in the shape of the lead-sheathed cable *C*. It flows along *C* until the track presents a better path, when it flows back to the rail again, as indicated by the arrows. Electrolytic action will occur where the current leaves the rail, the iron pipe, and the lead sheath of the cable. Fig. 10 shows a case where a cable and pipe run parallel to the iron rail *A B*, the arrows indicating the path of the

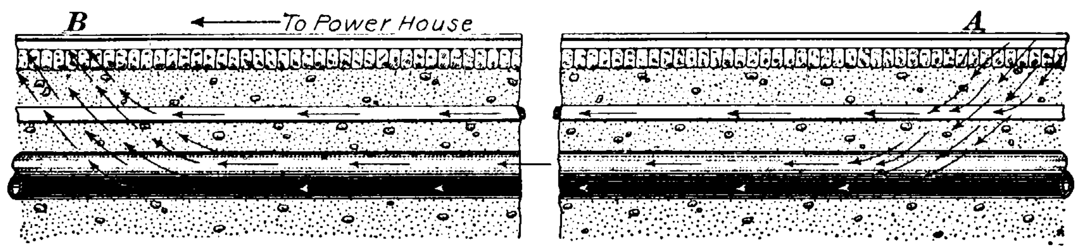

FIG. 10.

stray current. Lead-covered underground cables are particularly liable to damage, because lead is eaten away much more rapidly than iron; moreover, the corrosion never takes place evenly, but in spots, so that the pipe or sheath becomes pitted and is soon destroyed. Wrought-iron pipes are more quickly eaten than cast iron; in fact, the harder grades of cast iron, such as chilled iron, seem to be very little affected.

26. Influence of Resistance of Track Return.—It is easily seen, by referring to Fig. 8, that if the track return is in good condition, there will be little inducement for the current to leave the track and pass through the intervening earth to come back on the pipes. One of the most effective means, therefore, for preventing electrolysis is to see that the rails are thoroughly bonded. With the greater attention that is paid to good rail bonding on modern roads, there has been a corresponding reduction in the damage due to electrolysis.

27. Detection of Electrolysis.—As already stated, electrolysis occurs only when the current flows from the pipe or other conductor to the earth; in other words, the pipe or conductor must be at a higher potential than the surrounding earth. The dangerous points may, therefore, be located by going around to different parts of the system and taking readings of the voltage between the pipes or cables and the surrounding earth or neighboring pipes. If the pipe is positive to the ground, current will flow from the pipe to the ground; if, on the other hand, the pipe is negative and the earth positive, it shows that the current tends to flow towards the pipe and no harm is being done. After the dangerous localities have been located by means of these tests, return feeders can be run out to the danger points and attached to the pipes and track, so that the current will flow back on these feeders instead of leaving the pipes and causing damage.

28. Prevention of Electrolysis.—The ordinary precautions taken to prevent electrolysis on an overhead-trolley system have already been mentioned. The trouble is first localized near the station by connecting the positive pole of the dynamo to the line; next, the ground-return circuit is made as good as possible by thorough track bonding. Finally, tests are made to locate points where there is danger of electrolytic action and conductors run to these points to convey the current back to the station.

29. Systems Free From Electrolysis.—Systems using the double overhead-trolley and conduit systems, where the rails are not used as part of the return circuit, are, of course, exempt from trouble due to electrolysis. Roads operated by alternating current are also free from this trouble, but such roads are comparatively few in number.

30. Cars Operated on Three-Wire System.—Another scheme for preventing a great deal of the trouble due to electrolysis and at the same time using a higher line voltage is to operate the cars on the three-wire system, as shown in Fig. 11. *A* and *B* are the two tracks of a double-track road and *c*, *d* the two trolley wires. *G*, *G'* are two 500-volt generators connected in series and running the railway on the three-wire system. The track constitutes the neutral conductor, and it is evident that if the load on the two tracks is balanced, no current flows through the rails. The track return is called on to carry only the difference in the load, and as there are four rails to serve as a conductor, there is little tendency for the current to come back through pipes or other conductors. The use of this three-wire arrangement allows the power to be transmitted at 1,000 volts instead of 500, and therefore effects a saving in copper. The high pressure is, however, objectionable, especially in thickly populated districts, but it seems as if the system would be well adapted for cross-country and suburban lines. The

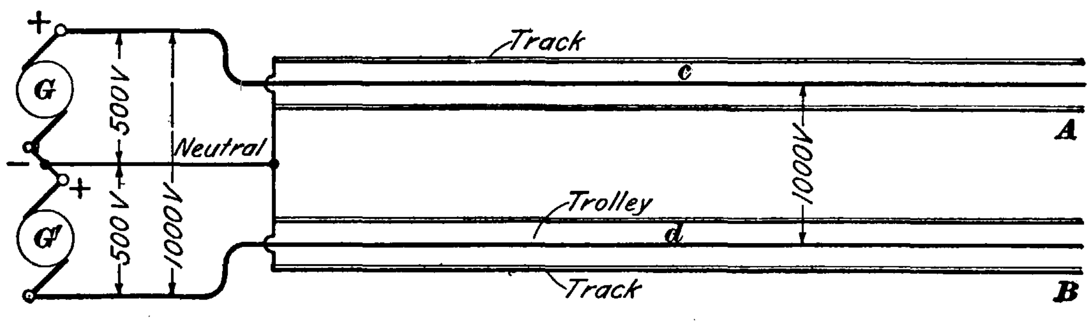

FIG. 11.

saving in copper is not as great as that effected in changing a two-wire lighting system to a three-wire system, because in the simple 500-volt trolley system the track is already utilized, whereas in the three-wire method of operation it is used very little. The saving in copper will, however, be from 20 to 40 per cent., depending on the quality of the track return.

Fig. 12 shows the three-wire system used on a single-track road. The trolley wire is here cut into sections, the length of which depends on the traffic. These sections are connected

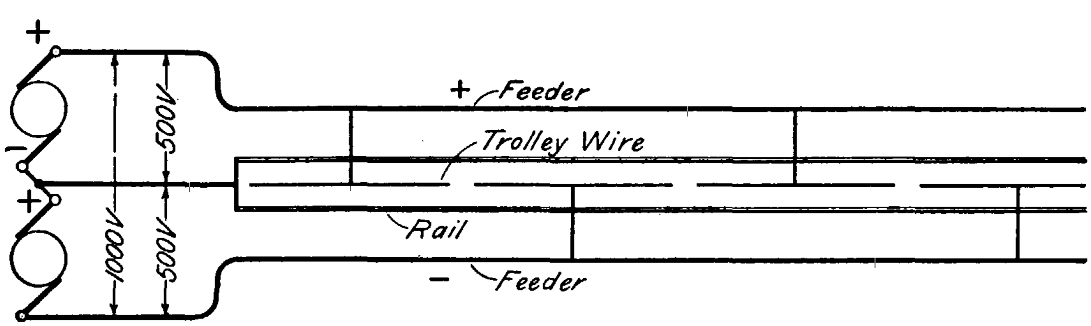

FIG. 12.

alternately to the two sides of the system and the track forms the neutral conductor. By choosing the length of the sections properly, the load on the two sides of the system may be balanced closely enough for all practical purposes.

LINE TESTS.

31. With the ordinary overhead-trolley system it is not, as a rule, necessary to make many tests of the overhead conductors. One side of these systems is always grounded, so that if a ground occurs at any point, due to poor insulation or any other cause, a short circuit results and the fault is either burned out or some indication is given, so that there is little difficulty in locating it. The insulation of the system may be measured by the voltmeter method.

There are, however, two special tests that are sometimes used in connection with electric railways that we will describe briefly. These are tests for defective rail bonds and track resistance.

32. Tests for Defective Rail Bonds.—Rail bonds are liable to work loose in time and develop bad contacts, and it is necessary to have some convenient means for detecting bad joints. Fig. 13 shows one device that may be used for this purpose. It consists of a flat wooden straightedge about 6 feet long provided with three spring contacts *a*, *b*, *c*. When this straightedge is laid on the track, contacts *a*, *b* span the joint and *b*, *c* a fixed length of rail. *V* is a millivoltmeter (a voltmeter reading to thousandths of a volt)

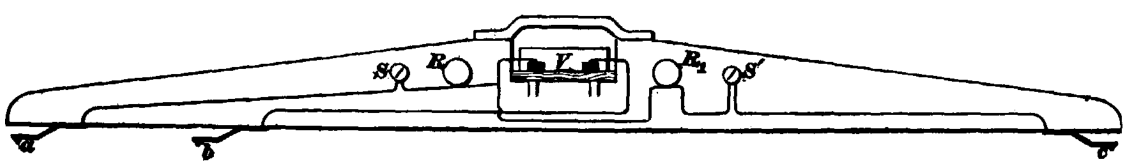

FIG. 13.

connected to the contacts *a*, *b*, and *c*, as indicated. *R* and R_1 are resistance coils of about 10 ohms each, and are used to prevent the connecting-in of the voltmeter from appreciably affecting the current in the rail. Small switches *S* and *S'* are provided, so that the voltmeter may be connected either between *a* and *b* or between *b* and *c*. The voltmeter should have the zero point at the center of the scale, so that the readings will be on opposite sides for currents through the two circuits. Now, when current is flowing through the rail and joint, the voltmeter reading between *b* and *c* will be proportional to the resistance of the section of rail between *b* and *c*, and when the voltmeter is switched to *a* and *b*, its reading will be proportional to the resistance of the joint. In this way, the resistance of any joint as compared with a fixed length *b c* of rail can be determined, and since the resistance that a good bond should have is known for the particular styles of bond in use, it is easy to determine just about what ratio the two voltmeter readings should bear to each other for a joint that is in good condition. If the reading across the joint is abnormally high as compared with that across the rail, the bond should be repaired.

33. Fig. 14 shows another method of detecting bad joints, which is similar in principle to the one just described. In this case a telephone is used for an indicator instead of a millivoltmeter. The telephone is a good instrument for this purpose, as it is very sensitive and is easily

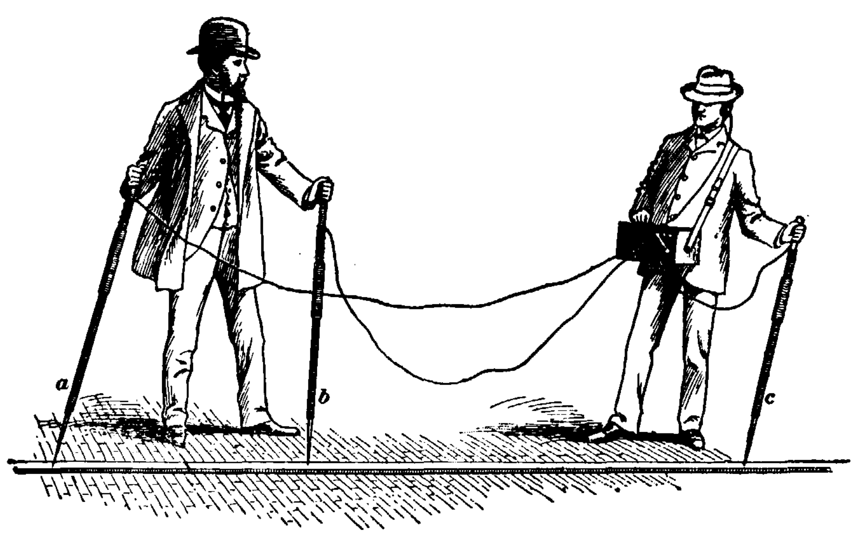

FIG. 14.

carried about. The operator on the left is provided with two poles having pointed metal terminals. Flexible wires lead from these terminals to the box carried by the second operator, who also carries a similar rod connected to the box, as shown. This box contains an interrupter that interrupts the current flowing through the head telephone worn by the operator, and thus causes the telephone to make a noise. Poles *a* and *b* are placed about 3 feet apart, so as to span the joint and fish-plate. Pole *c* is placed about 4 or 5 feet from *b*. By means of the switch the telephone is thrown first across one span and then across the other, the pole *c* being shifted until the sounds obtained for the two different positions are nearly the same in loudness. The switch on the box is then thrown to the middle position and the position of *c* more accurately adjusted, until little or no sound is heard in the telephone. When this condition of affairs is reached, the resistance of the length of rail between *b* and *c* is equal to the resistance of the joint between *a* and *b*. Since the weight of rail per yard is known, the resistance of the joint may be calculated from the known length *b c*. Usually, however, this will not be necessary, because the test is used principally for locating bad joints, and comparative results are what are looked for more than absolute measurements.

It will be noticed that the above test makes use of the current flowing in the rail, but is independent of the variations in this current, because the same current flows through both rail and joint. The use of the telephone instead of a voltmeter allows the tests to be carried out conveniently and rapidly. Fig. 15 shows the connections of this testing outfit. *A* is the vibrator, *B* the telephone, and *C* the three-point switch.

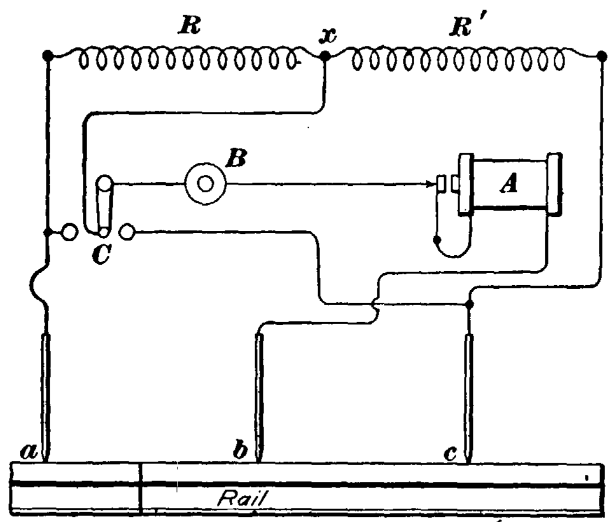

FIG. 15.

R and *R'* are two similar resistances. When the resistance between *a* and *b* is equal to that between *b* and *c*, it is evident that no current will flow through the telephone when *C* is on the middle point, because points *x* and *b* will be at the same potential.

34. Testing Resistance of Track-Return Circuit.—After a road has been in operation some time, it is often found that the drop on certain sections is larger than it should be, and it becomes necessary to remedy matters. The question naturally arises as to whether the track return is at fault or whether more copper is required in the overhead feeders. In order to find this out, it is necessary to know the comparative resistances of the two. If the track resistance is high compared with that of the overhead line, the track return needs attention, and *vice versa.*

Fig. 16 shows one method of measuring the resistance of a railway circuit. *F F* is the feeder running out to the section under consideration and *R R* the rail return. A time is selected at night, when traffic can be kept off the section

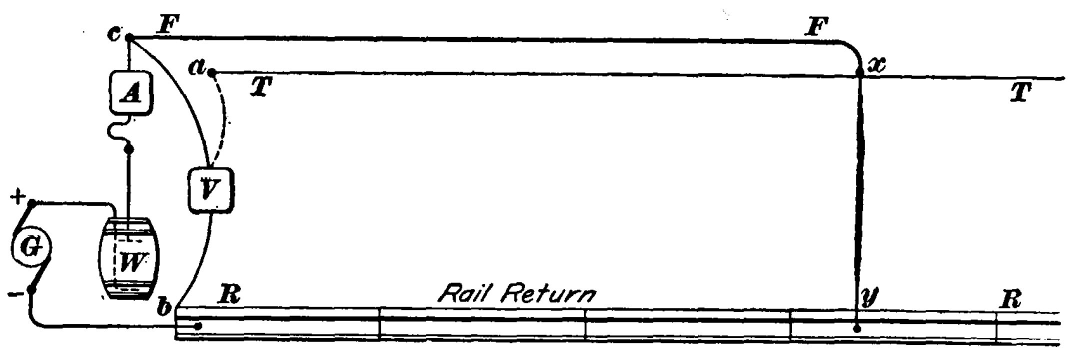

FIG. 16.

for a short time, and a water rheostat *W* is connected in series with the feeder *F* and the regular feeder ammeter *A*. The feeding-in point *x* is connected to the track by any convenient means, as shown at *x y*, and a steady current is sent through the circuit *G*+–*W*–*A*–*c*–*F*–*F*–*x*–*y*–*R*–*G*–. The drop through the entire feeder and rail circuit is measured by a voltmeter *V* connected to *c* and *b*. From the readings of *A* and *V*, the total resistance of the feeder and rail circuit is at once determined. The resistance of the feeder *F F* can be calculated from its known length and cross-section, and its resistance subtracted from the total resistance of the circuit will give the resistance of the track return.

The above method of finding the resistance of the track return assumes that there are no bad joints or unusually poor conductivity in any part of the feeder *F F*, but such is not always the case. If the trolley wire runs back to the power house or if there is another feeder nearby that can be used as a pressure wire, the drops in the feeder and track may be measured separately and an accurate idea gained as to just how the drop is distributed. For example, if the upper voltmeter terminal is connected to the end *a* of the trolley wire instead of to *c*, the reading obtained will be the drop through the track alone, because the voltmeter takes such a small current that there will be practically no drop through *Tx*. If one terminal of the voltmeter is connected to *c* and the other to *a*, the reading obtained will be the drop in the feeder *FF*. This method is the one to be preferred, because it at once gives an accurate comparison between the loss in the overhead work and the loss in the track and shows what part of the system requires attention in order to bring about better working conditions.

AUXILIARY EQUIPMENT.

35. We have already considered that part of an electric railway system that pertains directly to the supply of current for the cars. The rolling stock and car equipment remain to be considered, but before going on to this part of the subject, it may be well to pay some attention to what might be called the auxiliary departments of a road. Under this head may be included car houses or car barns, repair shops, etc. These, while not, perhaps, directly connected with the running of the cars, are at the same time an essential part of the road. Their equipment varies greatly on different roads, so that the descriptions can only be very general in character.

THE CAR HOUSE.

36. The **car house** or **car barn** is a building used for storing cars that are not in use; that is to say, either for storing the regular schedule cars during the hours when they are not in use or for storing closed cars in hot weather